1.0 Why Materials are Important

Air Force systems are extremely complex integrations of numerous materials and materials systems from high-temperature turbine engine blades to airframe structural composites. Thus, the selection of key design materials impacts critical issues of cost, strategic performance, and reliability. While these issues are somewhat interdependent, and their impact on Air Force systems is sometimes difficult to separate into individual roles, there are a number of common themes that will drive future developments. Key driving factors include the need to lower costs and improve affordability of both new and upgraded military systems, continued high-performance systems that assure military superiority, longer life and more reliable systems and components, and strategically important issues, such as better stealth materials and nonpolluting fluids and propellants. Finally, we believe that the Air Force needs to be the leader in novel materials R&D, such as computationally synthesized functional materials and computational materials processing. Research and development in these areas could lead to dramatically reduced time and cost of development through elimination of extensive testing and current practices of creating expensive data bases for design and manufacture. In summary, we envision research and development of new materials in the above areas will revolutionize the warfighting capabilities of the USAF.

1.1 Costs and Affordability

Affordability is a key criterion for assessing the value of new technology to determine the feasibility of incorporating it into military applications. We define affordability in terms of the life-cycle cost of a weapon system, including acquisition, materials and fabrication, operating/maintenance/assurance, and disposal costs. Although enhanced performance continues to be a high priority, improvements must be achieved with affordable technologies. This means that revolutionary materials and processes, which in some cases are more expensive than those currently in use, may have a favorable impact on a system's life-cycle cost and may also provide performance advantages.

1.2 Performance Issues

New materials offer improved performance by being lighter and by possessing specific functional (i.e., mechanical, electrical, and optical) properties. Of course, for a given thrust, decreased weight leads immediately to increased thrust-to-weight. However, when considering life-cycle costs, (i.e., costs of manufacture as well as engine flight hour maintenance and operational costs), one pound of engine weight saved can lead to a savings of 9 million gallons of fuel per engine over the life of the unit. The savings are immediately realized when considering jet fuel costs $0.55/gallon. Lighter materials play a significant role in reducing engine weight and therefore contribute directly to remarkable reductions in life-cycle costs. For example, the estimated weight of a compressor bladed ring made from existing materials is about 55 pounds, whereas the same component fabricated from Ti-based metal matrix composites would weigh 10 pounds, resulting in a significant savings.

In general, in gas turbine engines, thermodynamics are optimized by increasing the pressure of the air and the temperature of the combustion process. Hence, allowing higher operating temperatures will lead to increased efficiencies, which can be translated into either reduced specific fuel consumption or increased power. For example, if materials and innovative designs were available for compressors, for combustors, and for high-pressure turbines, increased compressor discharge, higher combustion temperatures, and high-pressure turbine inlet temperatures would markedly increase the efficiency of the engine. Materials improvement, in this context, should emphasize not only better mechanical properties but also improved resistance to corrosion and oxidation for extended times.

1.3 Reliability Issues

Repair and replacement of degraded or failed components can be extremely costly. For example, when a turbine disk is degraded by fatigue in the bore of the component, the whole disk is replaced, at a cost of $40K. Considerable savings might be effected by use of new materials with improved properties and with production methods that are more reliable. Furthermore, as described in the body of the report, changes in design to permit replacement of only the degraded part of the component may also lead to significant decreases in costs.

In terms of strategic implications, the fate of the F-16 fighter may be considered. At present, a serious failure involving a crack in the aft fuselage frame at the point of joining to the tail plane has been discovered. The solution is either to strengthen the frame–undesirable, but required in case of imminent threat–or to replace the rear frame assembly. The problem is that only a small fraction of the number of frames required to refit the fleet is available, and there is a significant probability that up to 700 planes will be grounded. This is a strategic nightmare, since fleet readiness is impaired markedly. In replacing these rear frames, new materials will be used, namely Al-Li alloys, which will be more reliable than the older alloys that were used originally. Also, these new alloys have lower densities and hence result in weight savings, which is an additional benefit.

1.4 Strategic Issues

Importantly, new capabilities, such as stealth, nonchlorine containing propellants, superemitters, and composites will allow missions to be performed with minimum detection and loss of aircraft and personnel.

1.5 Payoff From Novel Materials Development

There has been extremely exciting progress in computational methods to describe materials behavior, which will change the way materials will be developed and processed in the future. The progress is such that we envision predictive capabilities that will permit the design of new materials by computation, similar to the design development of the Boeing 777 aircraft. There are two advantages in this scenario: 1) The cost of alloy and materials development will be drastically reduced by eliminating expensive experimental programs of testing, and 2) brand new materials may be predicted and synthesized, which would not necessarily have been discovered by experiment. Coupling of computational and experimental methods will lead to detailed understandings of the properties of materials over many orders of magnitude of dimensional scale, atomic-, nano-, meso-, micro-, and macrostructure, as well as over a very wide range of time constants from atomic frequencies to hours. Concurrent to this computational development, there is an ongoing strong effort in new schemes for processing and synthesizing new materials. These materials are synthesized from the developments at the atomic/molecular level, are typically nano-scaled materials and composites, and offer revolutionary sets of properties. Successful implementation of these programs will lead to not only the application of new materials to existing aircraft platforms, but also the development of novel designs and technological approaches allowed by the unusual behavior of these materials to aircraft and space and missile systems.